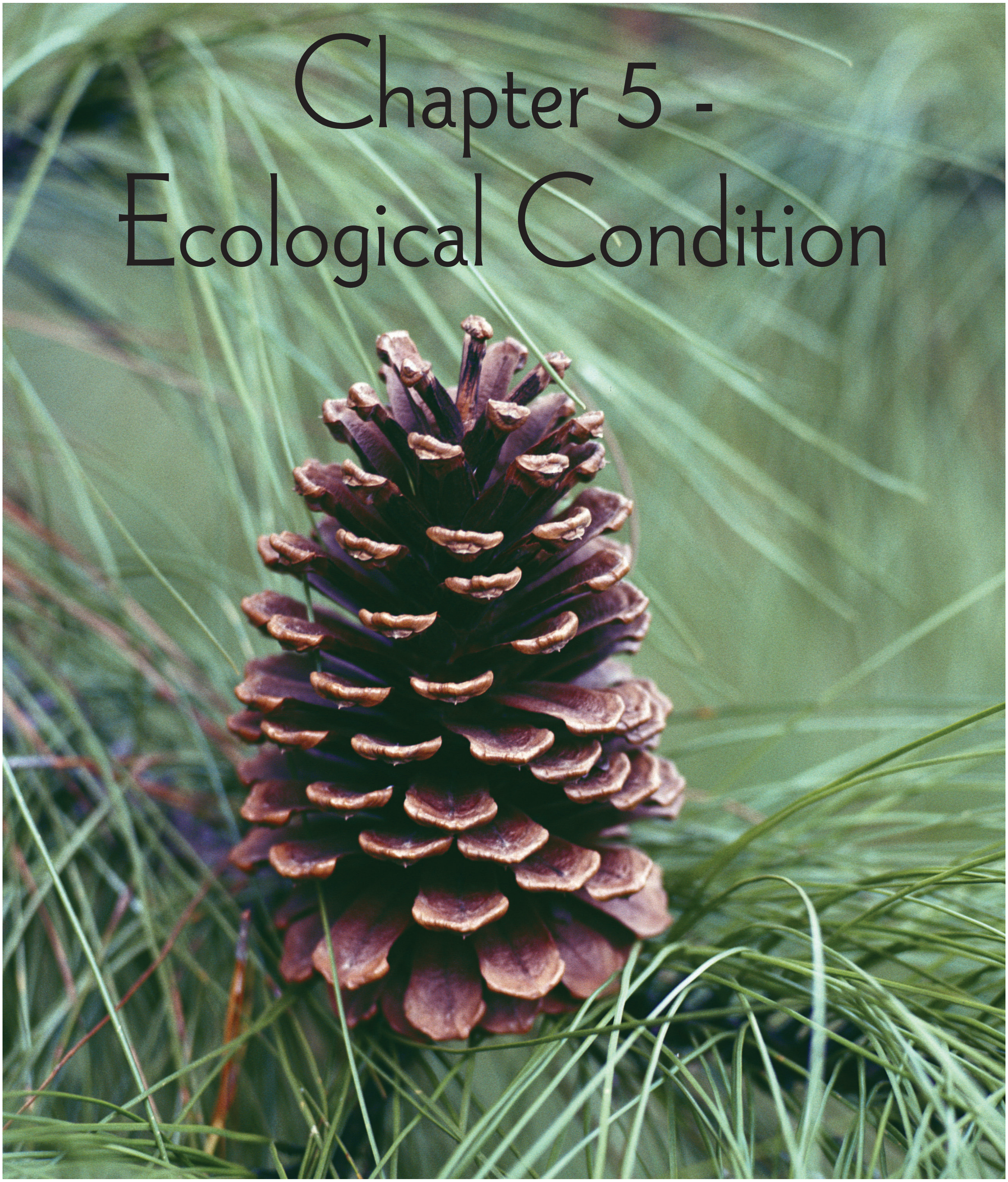
Chapter 5 - Ecological Condition



Introduction

Air, water, land—these are elements of "the environment" that the Environmental Protection Agency (EPA) seeks to protect. But assessing the state of the environment requires looking at a bigger picture. Air, water, and land are connected by natural cycles. For example, nitrogen-laden topsoil eroded from the Midwest may travel down the Mississippi River and pollute the Gulf of Mexico, or chemicals released to the air in the Great Lakes region may find their way into the waters in the Northeast. Living things inhabit virtually all of the nation's air, water, and land and are affected by innumerable natural and human events.

How can researchers, managers, policymakers, and the public track this big picture? One forward-looking way is to link the state of the nation's air, water, land, and living organisms into a broad framework termed "ecological condition"—the sum total of the physical, chemical, and biological components of ecosystems and how they interact. Ecological condition is ever changing, multifaceted, and specific to place and ecosystem. Understanding ecological condition is crucial because humans depend on, and are responsible for, the nation's ecosystems—forests, grasslands, shrublands, farmlands, urban and suburban environments, fresh waters, and coasts and oceans. These systems provide food, fiber, and shelter, as well as "housekeeping" functions ranging from water filtration and crop pollination to waste decomposition and recycling.

Trends in ecological condition, like disease trends described in Chapter 4 – Human Health, reflect the outcome of many different events and activities, both natural and human induced. Ecosystem condition is the result of natural resource management at national and state levels, local zoning and land use decisions, pollution and pollution prevention activities, natural disturbances, and many other factors. EPA is one of many federal, state, tribal, and local government and private partners working to understand ecological condition and to protect the nation's ecosystems. Most EPA programs focus on managing environmental stressors, such as minimizing chemicals in air and water or reducing toxic substances and hazardous waste. Measuring ecological condition will help EPA systematically assess how its management of stressors affects overall ecosystem health.

This chapter is organized around the framework of six essential ecological attributes developed by EPA's Science Advisory Board (SAB) (Exhibit 5-1): landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology and geomorphology, and natural disturbance regimes. Within each of these areas, indicators have been defined for each of the six ecosystem or land cover types identified by the H. John Heinz Center for Science Economics, and the Environment (Exhibit 5-2). The Technical Document for this EPA report describes each of these indicators, including the available data, data limitations, and data sources.[1]

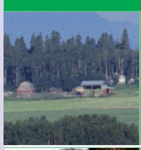
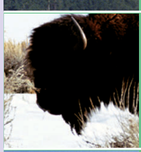
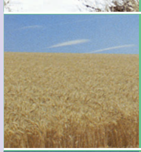
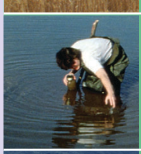
This chapter describes some of these indicators, including indicators for which national data are available and others for which national data are limited. In addition, the chapter illustrates some examples of promising approaches for using ecological condition to evaluate environmental protection efforts. The chapter closes by summarizing both the state of data for assessing ecological condition and key challenges.

Recent Ecological Condition Research Efforts

The chapter presents initial work toward identifying indicators to help answer the question, "What is the ecological condition of the United States?" This work draws primarily on two previous research efforts:

- *"Framework for Assessing and Reporting on Ecological Condition"[2] developed by EPA's Science Advisory Board (SAB). The SAB Framework designates "essential ecological attributes" (Exhibit 5-1) that provide a means to examine ecological condition as well as to consider the effects of stressors on condition.*
- *"The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States,"[3] a nationwide effort of government and the private sector led by The H. John Heinz III Center for Science, Economics and the Environment (The Heinz Center). Many of the indicators in this chapter and in the Technical Document accompanying this report are derived from the Heinz report.*

Exhibit 5-1: EPA Science Advisory Board essential ecological attributes

Essential Ecological Attribute	Description	Example Indicators
 **Landscape Condition**	The extent, composition, and pattern of habitats in a landscape.	- Status and change in extent of ecosystems
 **Biotic Condition**	The condition or viability of communities, populations, and individual biota.	- Imperiled species in the U.S. - At-risk native species - Trends in invasive and non-invasive birds in grasslands and shrublands
 **Ecological Processes**	Metabolic function of ecosystems - energy flow, element cycling, and the production, consumption, and decomposition of organic matter.	- Primary productivity - Movement of nitrogen
 **Chemical and Physical Characteristics**	Physical parameters (e.g., temperature) and concentrations of chemical substances (e.g., nitrogen) present in the environment.	- Nitrate, phosphate, and other chemical levels in streams
 **Hydrology and Geomorphology**	The interplay of water flow and land forms.	- Soil erosion - Change in stream flow rates
 **Natural Disturbance Regimes**	The historical function of discrete and recurrent disturbances that shape ecosystems.	- Forest disturbances: fire, insects, and disease

Source: EPA, Science Advisory Board. *Framework for Assessing and Reporting on Ecological Condition*. June 2002.

Exhibit 5-2: Ecosystem types as described by The Heinz Center

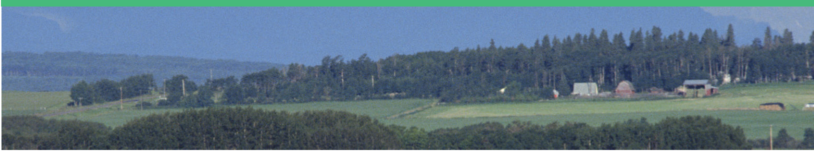
Ecosystem Type	Description
Forest Lands	Lands at least 10 percent covered by trees of any size, at least 1 acre in extent.
Grasslands and Shrublands	Lands in which the dominant vegetation is grasses and other non-woody vegetation or where shrubs (with or without scattered trees) are the norm. This ecosystem type includes bare rock deserts, alpine meadows, and arctic tundra.
Farmlands	Lands used for production of annual and perennial crops and livestock and areas on the larger farm landscape (e.g., field borders and windbreaks, small woodlots, grasslands and shrubland areas, wetlands, farmsteads, small villages and other built-up areas) within or adjacent to croplands.
Urban and Suburban	Places where the land is primarily devoted to buildings, houses, roads, concrete, grassy lawns, and other elements of human use and construction.
Fresh Waters	Rivers and streams, including those that flow part of the year; lakes, ponds, and reservoirs; ground water; fresh water wetlands, vegetated margins of streams and rivers (riparian areas).
Coasts and Oceans	Estuaries and ocean waters under U.S. jurisdiction Estuaries are partially enclosed bodies of water (including bays, sounds, lagoons, and fjords) considered to begin at the upper end of tidal or saltwater influence and end where they meet the ocean.

Source: The Heinz Center. *The State of the Nation's Ecosystems.* 2002.

What is the ecological condition of the United States?

Basic questions about the health of the nation's ecosystems and the overall ecological condition of the U.S. have proven difficult to answer in a few summary statements. Ecosystems are dynamic assemblages of organisms that change and adapt continuously to a variety of natural disturbances and stressors, such as fires and floods, as well as to pollutants and land use changes. A variety of ecosystem management practices are used to support human survival and economic growth.

Because of these complexities, measuring ecological condition goes beyond monitoring air or water to determine whether pollutant concentrations or temperatures exceed a legal standard. Trying to characterize overall condition by looking at only one factor, such as stressors, is like the blindfolded men trying to describe an elephant after touching only one part of the animal. In the same way, we cannot determine the overall condition of an ecosystem by looking at isolated environmental measures, such as insect outbreaks in a forest, chemical concentrations in water, or declines in the number of certain species. Assessments of ecological condition must incorporate measures of different characteristics, potentially at different times and different places within a system. The importance of multidimensional measurements to understand multidimensional systems is described in more detail in "Ecological Condition as an Environmental Result" later in this chapter. This section illustrates indicators that provide insights into the six attributes identified by the Science Advisory Board.



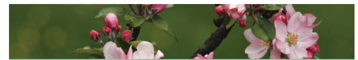
Landscape Condition

Landscape condition, a term that applies to both terrestrial and aquatic ecosystems, includes such aspects of ecosystems as extent, age, composition, and juxtaposition with other land cover types and land uses. Landscape condition determines, in part, the ability of ecosystems to sustain themselves, as well as respond to human needs—for example, to supply crops and timber, fish and shellfish, clean water and air, and wildlife nurseries. This section focuses on one aspect of landscape condition—extent. Indicators addressing age, composition, and patterns of ecosystems are described in the accompanying Technical Document.

Extent provides basic information on how much of an ecosystem exists, where it is, and whether it is shrinking or expanding. Changes in the extent of various cover types in the U.S. have been driven primarily by human land (and water) uses over the past 400 years (Exhibit 5-3). As of 1997, approximately 25 percent of forests, 3 to12 percent of grasslands and shrublands, and more than 50 percent of wetlands, had been converted to other uses since European settlement.[4,5,6]

Most of the changes in ecosystem acreage since the 1980s have stemmed from agriculture and development activities. Between 1982 and 1997, approximately 7 million acres of agricultural land and 10 million acres of forest land were converted to residential, transportation, industrial, urban, and other uses.[7] Another 22 million acres of pasture and rangeland (including some grasslands and shrublands) were converted to crop production.[8]

Only limited information exists on the total extent of water ecosystems, both fresh water and coastal, other than wetlands. Small streams may disappear because of mining, damming, or water withdrawals. However, because there is no widely accepted way to classify streams for ecological monitoring, no national dataset exists for reporting on their gains or losses.[9] The extent and composition of most, but not all, of the nation's coastlines have been established by the National Oceanic and Atmospheric Administration.[10] Eight percent or 400,000 acres of coastal wetlands were converted to other uses between the mid-1950s and mid-1990s.[11] For coral reefs, shellfish beds, and submerged aquatic vegetation, baseline information is inadequate, although a survey in Chesapeake Bay indicated that acres of submerged aquatic vegetation have increased from 41,000 to 69,000 since 1978.[12] The structure and pattern of estuarine landscapes, and their contribution to ecological condition, remain inadequately measured or understood.



Landscape Condition Indicators

Extent of ecosystem/land cover types (forests, farmlands, urban/suburban, grasslands/shrublands, fresh waters, coasts and oceans)

The changes in ecosystem acreages described above may represent a small percentage of a specific cover type on a national basis. In some cases, however, even small changes can have direct effects on species associated with ecosystems locally. NatureServe, a non-profit organization that tracks species diversity and loss nationwide, has stated that loss of habitats due to changes in extent of land cover constitutes the single greatest threat to species survival.[13]

As land use and acreage change, the mix of living things and ecosystem types also change, with uncertain ripple effects. Wetland ecosystems, for example, are critical to the life cycles of plants, fish, shellfish, migratory birds, and other wildlife. More than one-third of threatened and endangered species in the U.S. live only in wetlands, and nearly half use wetlands at some point in their lives.[14] Forested wetlands often become shrub wetlands after the trees are removed, and these two types of ecosystems do not support the same plants and animals. Over the last 50 years, the amount of non-stocked forest has decreased, while the amount of forest with older trees has increased.[15] (For more information on these effects, see Chapter 2 – Purer Water and Chapter 3 – Better Protected Land.)

Exhibit 5-3: Historical and current extent of land cover classes

Land Cover Class	Pre-European Acreage Estimate	1977-1982 Acreage Estimate	1997-2002 Acreage Estimate
Forest Lands	1 billion[b]	744 million[b]	749 million[b]
Grasslands and Shrublands[a]	900 million - 1 billion[c]	872 million (based on loss of 11 million acres of non-federal)[d, e]	861 million (an additional 205 million in Alaska)[d]
Farmlands (Acreage Shown is for Croplands and Pasturelands)[a]	0	553 million[e]	530 million[e]
Urban and Suburban (Acreage Shown is for Developed Lands)[a]	0	73 million[f]	98 million[f]
Fresh Waters	No data	No data	41.6 million acres of lakes, ponds, and streams[g] 60.2 millions acres - Great Lakes[g] 3.7 million miles of streams and rivers[a, g]
Wetlands[a]	221 million[h]	106.1 million[h]	105.5 million[h] (Alaska: 170 million acres)[i]
Coasts and Oceans	No data	No data	57.9 million acres of estuarine surface area[j] 66,645 miles of coastline[j]

Note: All estimates are in acres.

a Does not include Alaska.

b USDA, Forest Service. *U.S. Forest Facts and Historical Trends*. April, 2001 and USDA, Forest Service. Draft Resource Planning Act Assessment Tables. May 3, 2002 (updated August 12, 2002). (September 2003; *http://www.ncrs.fs.fed.us/4801/FIADB/rpa_tabler/Draft_RPA_2002_Forest_Resource_Tables.pdf*).

c Klopatek, J.M., et al. *Land use conflicts with natural vegetation in the United States*. 1979.

d The Heinz Center. *The State of the Nation's Ecosystems. 2002*.

e USDA, Natural Resources Conservation Service. *Summary Report: 1997 National Resources Inventory (revised December 2000)*. 2000.

f USDA, Natural Resources Conservation Service. *National Resources Inventory: Highlights.* 2001.

g Environment Canada and EPA. *The Great Lakes, an Environmental Atlas and Resource Book*. 1995.

h Dahl, T.E. *Status and Trends of Wetlands in the Conterminous United States: 1986 to 1997*. U.S. Fish and Wildlife Service. 2000.

i Dahl, T.E. *Wetlands Losses in the United States 1780's to 1980's*. 1990.

j EPA, Office of Water. *The Quality of Our Nation's Waters, A Summary of the National Water Quality Inventory: 1998 Report to Congress.* 2000.

Biotic Condition

Every ecosystem contains living components; their very presence or absence, along with their diversity, signals the capacity of a place to support life. Because living organisms respond to multiple factors, their condition—known as biotic condition—provides a snapshot of many other conditions within their environment. Thus, indicators of biotic condition, such as species at risk, competition from non-native species, or rates of disease and deformity, are vital to assessing ecological condition.

Currently, the data to support such indicators are limited, and no data are available to accurately measure biotic condition on a national basis. Data do exist on a small fraction of the total number of native species in the U.S. and on the presence of "invasive" bird species in grassland and shrubland ecosystems. Additionally, data on forest lands in 37 states provide a partial view of tree condition as an indicator of biotic condition. This section summarizes the data available for these measures of biotic condition.

Biotic Condition Indicators

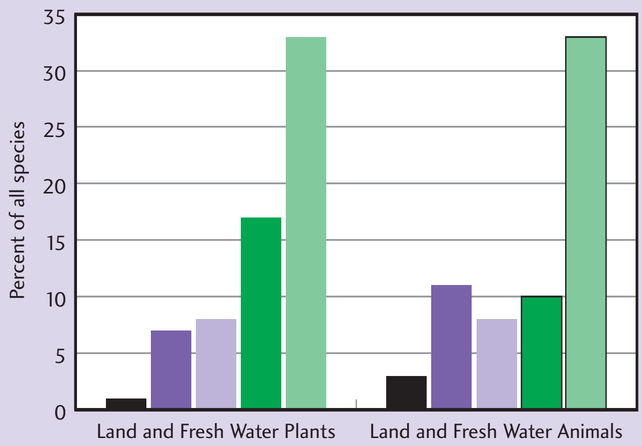
At-risk native species

Benthic Community Index

Population trends of invasive and native non-invasive bird species

Tree condition

Exhibit 5-4: At-risk land and fresh water plant and animal native species, 2000



Coverage: all 50 states.

Source: The Heinz Center. *The State of the Nation's Ecosystems.* 2002. Data from NatureServe and its Natural Heritage member programs.

Roughly 200,000 native plant, animal, and microbial species inhabit the U.S.[16] NatureServe is tracking approximately 16,000 native plant and 6,000 native animal species. Of these, about 19 percent of the animal and 15 percent of the plant species are estimated to be imperiled or critically imperiled, as shown in Exhibit 5-4.[17] (Note that the ranking criteria, evidence requirements, taxonomic coverage, and purposes for gathering this information vary from those of the Endangered Species Act, and thus the categories do not match official "threatened and endangered" species listings.[18]) Increased risk levels for a particular species may be due to historical or recent population declines or may reflect natural rarity.[19]

Imperiled species have been examined by ecosystem. Fresh water species show the highest rates of imperilment (Exhibit 5-5).[20] One percent of plants and 3 percent of animals may already be extinct.[21]

Birds, which are highly mobile (and "monitored" by many people for pleasure), respond quickly to environmental change. Changes in the mix of native and alien—and invasive and non-invasive—birds often signal changes in grassland and shrubland condition. The presence of native non-invasive species generally reflects relatively intact, high-quality native grasslands and shrublands. Conversely, increases in both native and non-native invasive species, such as American crows or European starlings, often accompany land conversion to agriculture or grazing uses, landscape fragmentation due to suburban and rural development, and the spread of

Exhibit 5-5: Percent of imperiled species by ecosystem, 2000

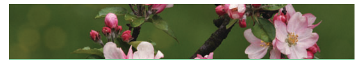
Land Cover Class	Number of Animal Species	Percentage Imperiled Species	Percentage Critically Imperiled Species	Percentage Presumed/Possibly Extinct
Forest Lands	~ 1700	5%	3.5%	1.5%
Grasslands and Shrublands	~ 1700	6%	3.5%	0.5%
Farmlands	–	–	–	–
Urban and Suburban Ecosystems	–	–	–	–
Fresh Water Ecosystems	~ 4000	8%	13%	4%
Coasts and Oceans	–	–	–	–
All U.S.	22,000 plant and animal species	15% of plants and 19% of animals		1% of plants and 3% of animals

Source: Based on the Heinz Center. *The State of the Nation's Ecosystems.* 2002. Data from NatureServe and its Natural Heritage member programs.

exotic vegetation.[22] From the mid-1960s until the last half-decade, invasive and non-invasive bird species changed in similar proportions in grasslands and shrublands. From 1996 to 2000, however, the population of birds representing invasive species climbed steeply.[23] This increase might represent a short-term fluctuation in bird populations, or it could signal changes in grassland and shrubland ecosystem condition.

The health and physiology of individual organisms are also signs of ecosystem condition. In an assessment of forest condition, for example, data from the U.S. Department of Agriculture (USDA) Forest Service Forest Health Monitoring Program (currently available for only 37 states) examined the number of dead or dying trees, the number of forests with thin canopies, and the extent to which buildup of flammable material threatened to alter the ecosystem significantly. Although the data are insufficient to assess 39 percent of forested areas, analyses show that nearly 41 percent of sampled trees were in fair or good condition and 20 percent were in poor condition.[24]

Chemical and Physical Characteristics



Chemical and Physical Characteristics Indicators

Nitrate levels in streams by ecosystems

Chemical and physical properties, like other non-living ecosystem attributes, help shape the environment of living things. Many of EPA's specific environmental protection responsibilities include measuring and addressing chemical changes. Chemical measurements are often based on water sampling for, among other substances, nitrogen and phosphorus compounds, dissolved oxygen, pesticides, and heavy metals.

Some data on chemical characteristics in U.S. waters have been collected by the U.S. Geological Survey National Water Quality Assessment (NAWQA) program. In an analysis done for the Heinz report, NAWQA reported on contaminants in stream waters from 109 sites and in sediments from 558 stream sites in 36 watersheds across the U.S. At least half of monitored streams had contaminant concentrations that exceed water quality criteria for wildlife.[25] However, no analyses yet relate these concentrations to the status of fish or invertebrate communities in the streams. Nitrate levels were highest in farmland streams, with 10 percent of the samples exceeding drinking water standards (Exhibit 5-6).[26]

The NAWQA program provides consistent and comparable information on nutrient and pesticide concentrations in streams in agricultural areas, although the network design and number of sites do not allow estimates to be made for agricultural streams nationally. Nitrate loss from most forests does not appear to be resulting in high-nitrate concentrations in forest streams, but few streams are sampled in parts of the country where nitrate deposition tends to be high (e.g., eastern states).

A number of physical and chemical indicators are being monitored in Atlantic and Gulf Coast estuaries to help diagnose and interpret information on biotic condition. Eighteen percent of mid-Atlantic estuaries show high nitrogen concentrations, and 12 percent show high phosphorus concentrations. Twenty percent of Atlantic and Gulf Coast estuaries have low dissolved oxygen concentrations (i.e., less than 5 milligrams per liter). On average, 75 percent of the sediments contain elevated pesticide concentrations, and 40 percent show elevated concentrations of heavy metals.[27]

Exhibit 5-6: Nitrate levels in streams by ecosystem, 1992 - 1998

Land Cover Class	Number of Streams Sampled	Nitrate Levels
Forests	36	50% < 0.1 mg/L 75% < 0.5 mg/L 3% > 1.0 mg/L (1 sample)
Grasslands and Shrublands	No data	No data
Farmlands	50	50% < 2.0 mg/L 10% > 10 mg/L (exceeds drinking water standard)
Urban and Suburban Ecosystems	21	40% > 1.0 mg/L 25% < 0.5 mg/L 3% < 0.1 mg/L

Source: USGS, National Water Quality Assessment. *The Quality of Our Nation's Waters–Nutrients and Pesticides*. 1999.

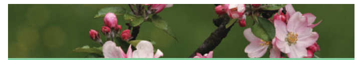
Ecological Processes

Ecological processes comprise the cycling of chemicals and energy through ecosystems. Like the flow of raw materials and labor through a factory, these processes keep ecological systems running. Ecosystems are solar powered: plants turn energy from the sun, carbon dioxide from the air, and nutrients from the soil into food for other organisms. Water and nutrients such as carbon and nitrogen—fundamental building blocks of living tissue—also cycle continuously through ecosystems. Changes in nutrient cycles or disruption in water cycles not only affect the operation of an ecosystem locally, but also may reach well beyond ecosystem boundaries.

The amount of solar energy captured by plants is a key indicator of ecosystem function.[28,29] The energy brought into an ecosystem is a key factor in determining the amount of photosynthesis, and the amount of plant growth that occurs each year.[30] Plant growth may increase under plant-friendly conditions, for instance, when rainfall or nutrients increase, or it may decrease under stressful conditions, as in the presence of toxic substances or disease. Changing growth affects, and additionally may change, the way ecosystems function, altering yields of crops and timber, and the diversity and mix of animal and other species.

For the 11-year period between 1988 and 2000, annual estimates of plant growth reveal no overall trend for any land cover type or any region of the U.S., although they do fluctuate year to year by as much as 40 percent of the 11-year average.[31] Long-term monitoring will be required to separate consistent trends from year-to-year variability caused by rainfall and other factors. No estimates yet exist for phytoplankton or submerged vegetation in fresh water or coastal systems.

Nitrogen is a critical element for plant growth and a basic constituent of proteins. In excess, however, it can make soil conditions less favorable for plant growth, damage aquatic life, and impair human health. Although nitrogen gas makes up nearly 80 percent of Earth's atmosphere, organisms cannot use it until it is converted to active forms by nitrogen-fixing bacteria, fertilizer production, or fossil fuel combustion. Over the past century, the forms of nitrogen traveling through air, water, and soil have changed dramatically, leading to ecosystem effects.[32] Nitrogen compounds falling in rain acidify soils and surface waters and can stimulate heavy growths of algae, which may take up so much oxygen that few other organisms survive. Nitrogen compounds can leach into and contaminate ground water used for drinking and have harmful effects in surface water systems. Movement of excess nitrogen from agricultural sources in the upper Mississippi River basin, for example, has been correlated with high levels of plant productivity (eutrophication) and a lack of oxygen (hypoxia) more than 1,000 miles downstream in the northern Gulf of Mexico.[33] The lack of oxygen kills fish, shrimp, and bottom-dwelling communities, causing economic losses to commercial fisheries and diminishing regional biodiversity.



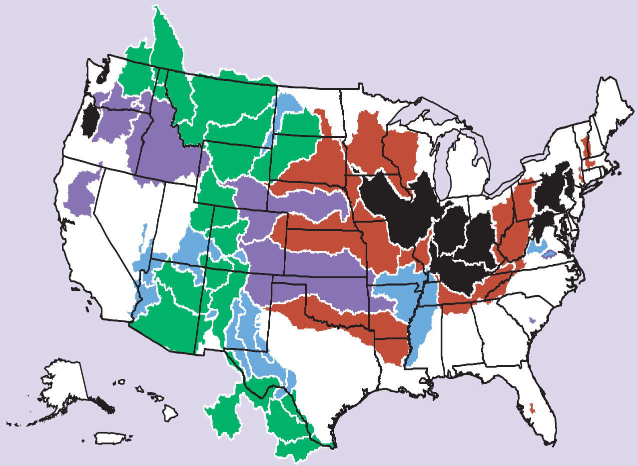
Ecological Processes Indicators

Terrestrial Plant Growth Index

Movement of nitrogen

Biologically active forms of nitrogen enter the air as pollutants from industrial facilities, cars, and feedlots and then pass into ecosystems via plants, soils, and water bodies. Nitrogen from septic tanks, animal waste, and excess fertilizer also leaches into the soil and ground water or runs off the land, moving through streams, rivers, and lakes until it eventually reaches estuaries. Some enters streams directly from wastewater treatment plants, and some is lost again to the atmosphere as it moves downstream. The yield of nitrogen in runoff varies in different parts of the country, reflecting differences in atmospheric deposition, fertilizer use, population density, and ecosystem characteristics. An analysis of estimated nitrogen yield shows that watersheds in the upper Midwest and Northeast experience between 4.7 and 15.6 pounds of nitrogen in runoff per acre per year, but watersheds in the mountains of the West yield less than 10 percent of that amount (Exhibit 5-7).[34]

Exhibit 5-7: Yield of total nitrogen from major watersheds, 1996-1999



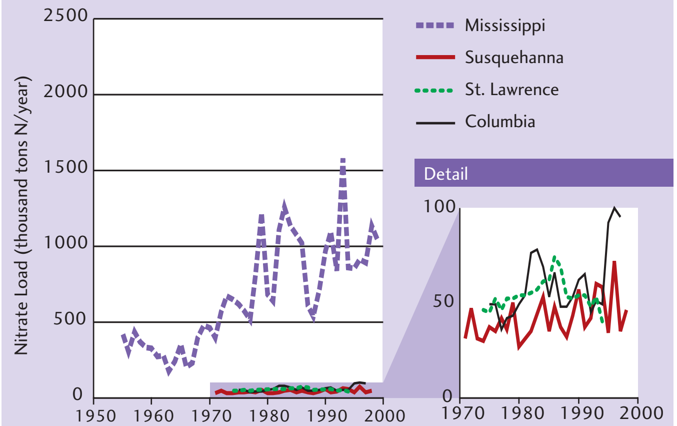
Total Nitrogen (pounds of nitrogen per acre per year)

Data Not Available
Less than .02
.02–0.9
0.9–2.3
2.3–4.7
4.7–15.6

Coverage: selected areas of lower 48 states.

Source: The Heinz Center. *The State of the Nation's Ecosystems.* 2002. Data from three U.S. Geological Survey efforts: the National Stream Quality Network, the National Water Quality Assesment, and the Federal-State Cooperative Program.

Exhibit 5-8: Nitrate load carried by major rivers, 1950s-2000



Coverage: selected major rivers.

Source: The Heinz Center. *The State of the Nation's Ecosystems.* 2002. Data from three U.S. Geological Survey efforts: the National Stream Quality Network, the National Water Quality Assessment, and Federal–State Cooperative Program.

The *yield* of nitrogen from major watersheds is characterized as pounds of nitrogen per acre of watershed area that enters rivers and streams through discharges, runoff, and other sources. The *load* of nitrate, a common form of nitrogen, from major rivers is defined as the tons of nitrate carried to the ocean each year by the four largest U.S. rivers.[35]

Nitrate load in the Mississippi River has been monitored since the mid-1950s and from the Susquehanna, St. Lawrence, and Columbia rivers since the 1970s. The Mississippi drains the nation's midwestern breadbasket, where fertilizer use and soil erosion are often high. Although fluctuating from year to year, the Mississippi's nitrate load has increased from approximately 250,000 tons per year in the early 1960s to approximately 1 million tons per year during the 1980s and 1990s (Exhibit 5-8).[36] Nitrate loads in the other three rivers have oscillated around 50,000 tons per year since the 1970s, although the Columbia River spiked to 100,000 tons per year in the late 1990s.[37]

Hydrology and Geomorphology

Like the framing of a house, the properties, distribution, and circulation of water (hydrology) and the relief features of the earth's surface (geomorphology) help give environments their character. The quantity and timing of water flows influence many ecosystem parts and processes, including those with direct effects on human activities. Loss of topsoil, which can take millennia to replenish, has obvious implications for agriculture, and moving sediment can cause sedimentation in harbors and other facilities and can carry chemicals for long distances.

High and low water flows have important implications for ecosystem health. Low water flows define the smallest area available to stream biota during the year, and high flows shape stream channels and wash out silt and debris. Some fish depend on high flows for spawning. The timing of high and low flows affects the status of aquatic species as well as human water supplies and the flooding of farms, towns, and cities. Climate, dams, water withdrawals, and changes in land use all affect the flow of water.

High and low flows for 867 streams and rivers with appropriate data (records between 1930 and 1949, and during the 1970s, 1980s, and 1990s) show little change from the 1970s to the 1990s.[38] The same is true for the timing of high and low flows. However, the number of streams with high flows well above their historic (1930 to 1949) rates rose markedly from the 1980s to the 1990s.[39] This increase may be attributable, in part, to earlier droughts, but may also be linked to widespread changes in land use.

Erosion can also have significant effects on ecosystem condition. Wind and water erode soils naturally, changing the character of the landscape. Human activities such as development, road construction, timber harvesting, and agricultural practices that disturb the soil surface or remove anchoring vegetation increase the potential for erosion. Soil loss not only reduces soil quantity and quality but can degrade water quality by carrying nutrients, pesticides, and other contaminants downstream. Sedimentation can raise costs to maintain reservoirs, navigation channels, and water treatment plants and can degrade habitat for aquatic organisms.

Hydrology and Geomorphology Indicators

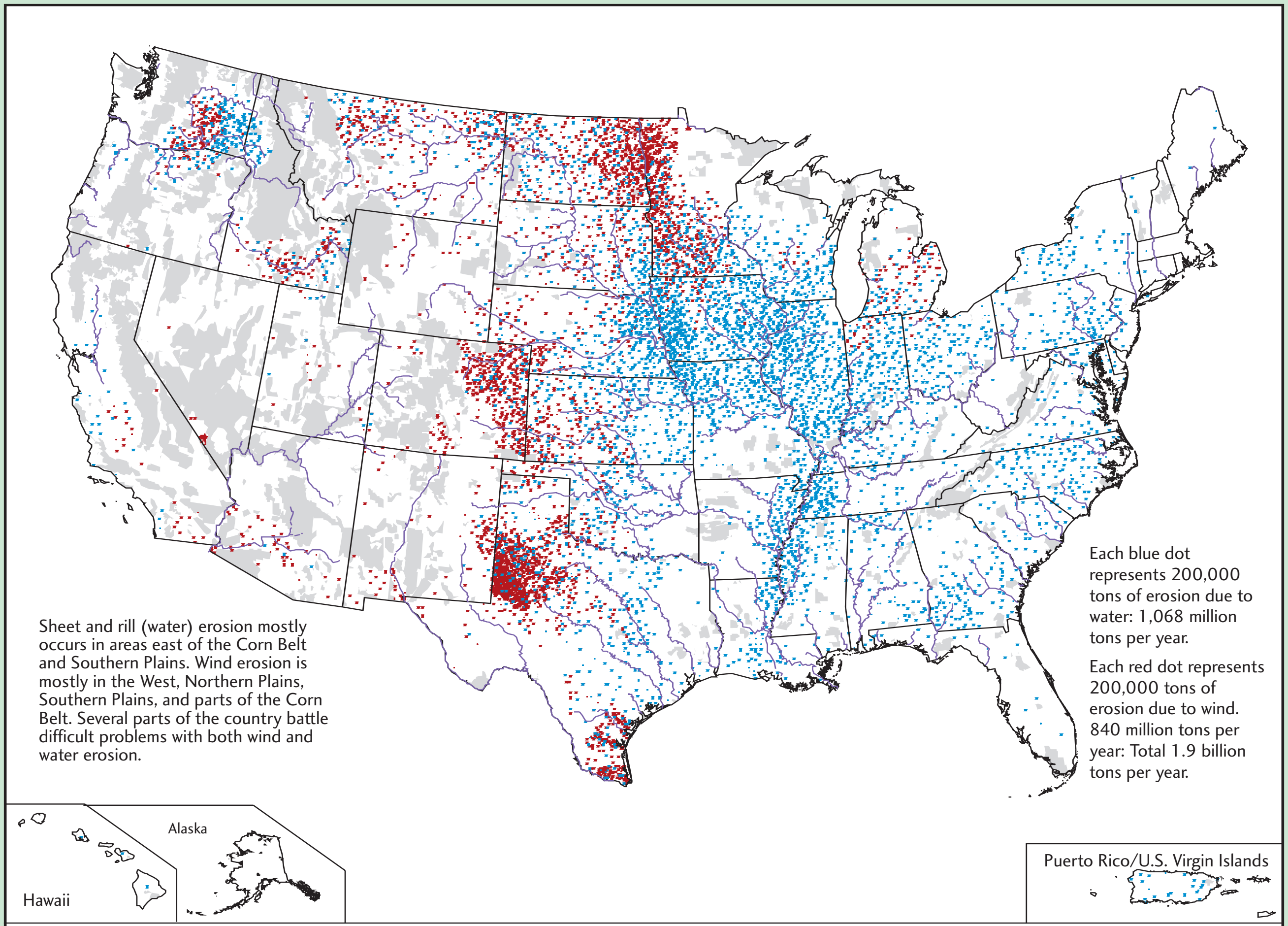
Changing stream flows

Soil erosion

Reductions in erosion can occur through improved tilling or management practices, removal of marginal land from production, and land conservation efforts like the Conservation Reserve Program (CRP). Reducing erosion contributes not only to improved soil quality but also to improved water quality in adjacent and downstream aquatic ecosystems.

Data on the 409 million acres of croplands and CRP lands show that erosion from water and wind decreased from a total of more than 3 billion tons per year in 1982 to about 1.9 billion tons in 1997.[40] (Not all of this soil actually moved offsite.) The croplands and CRP lands experiencing erosion in 1997 are shown in Exhibit 5-9. About 15 percent of U.S. cropland and CRP land is estimated to have a high potential for wind erosion, based on an analysis of several factors including soil properties, landscape characteristics (e.g., vegetative cover, rainfall), and management practices (e.g., wind barriers, terracing). This represents a decrease in acreage of almost 33 percent between 1982 and 1997.[41] The acreage with the highest potential for water erosion, based on similar factors, also decreased by about 33 percent to 89 million acres. This represents about 22 percent of U.S. cropland.[42]

Exhibit 5-9: Wind and water erosion on croplands and Conservation Reserve Program (CRP) lands, 1997



Note: Alaska is not covered by the National Resources Inventory.

Source: USDA, Natural Resources Conservation Service. National Resources Inventory, 1997, revised December 2000: Total Wind and Water Erosion, 1997. December 5, 2000 (April 11, 2003; *http://www.nrcs.usda.gov/technical/land/meta/m5112.html*).

Natural Disturbance Regimes

Disturbance and change, particularly over long periods of time, are part of all ecosystems. Natural disturbances, from ice ages to droughts, can alter ecosystem characteristics. Some attributes of ecosystems depend on various types of disturbances—for example, some coniferous species depend on fire to open cones and clear ground cover for germination and growth of native species.

Understanding the roles that natural disturbances play in the evolution of ecosystems is key to determining how land use and management practices can improve ecosystem conditions. For example, an unprecedented epidemic of Southern Pine beetle currently is damaging many forests in the southeastern U.S. Understanding this pest and its disturbance patterns can assist in developing appropriate responses to restore ecological balance. The extensive acreages burned from wildfires in the western U.S. in recent years pose similar forest ecosystem challenges and opportunities for developing appropriate responses.

There have been few attempts to document regional or national natural disturbance regimes as indicators. The USDA Forest Service Forest Health Monitoring Program is an exception. Statistical data from the forest inventories conducted between 1979 and 1995 have been used to establish short-term baselines for natural disturbances such as climatic events, fire frequency, and insect and disease outbreaks. Several recent events proved to be outside the range of natural disturbance patterns in the 1979 to 1995 timeframe, including:

Natural Disturbance Indicators

Forest disturbances: fire, insects, and disease

- El Niño from 1997 to 2000.
- Northeast ice storm in 1998.
- Spruce beetle outbreak in 1996, Spruce budworm outbreak in 1997, and a Southern Pine beetle outbreak in 2000.
- National acres burned in 2000 and the area burned in the West in 1996, 1998, and 2000.[43]

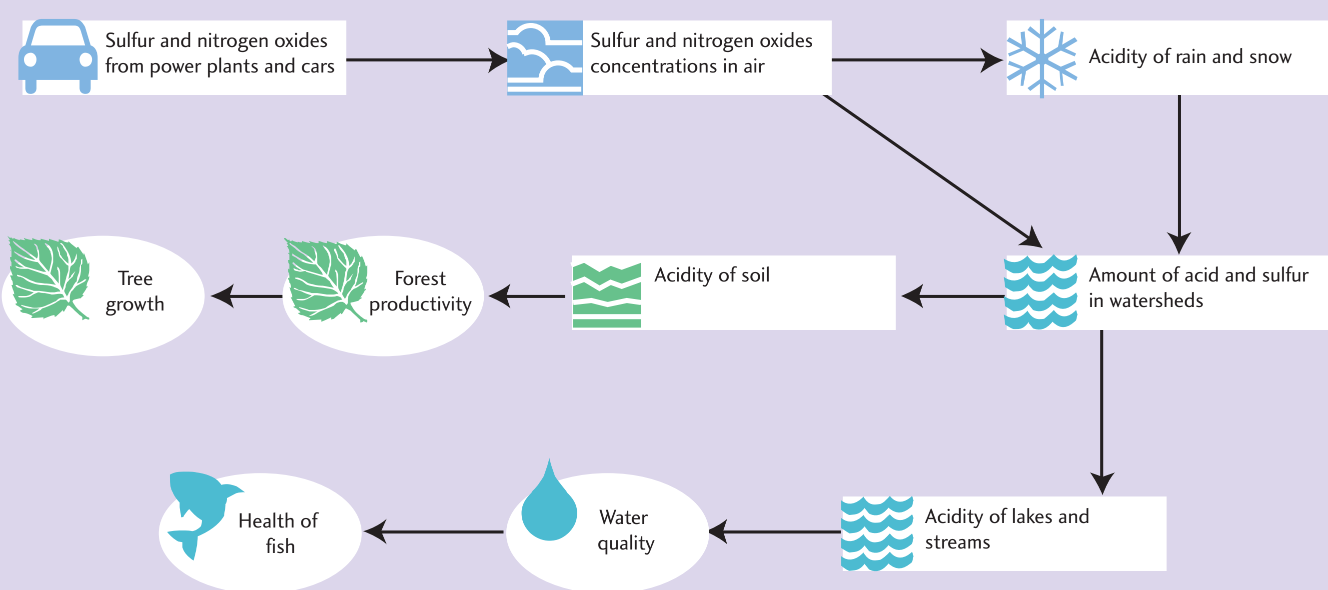
Disturbance regimes can be changed by resource management. For example, in the two decades between 1980 and 1999, wildfires burned between 2 million and 7 million acres annually, down from a high of 52 million acres in 1930.[44] The decline is primarily due to fire suppression policies.[45] Wildfires in 2000, however, reached 8.4 million acres.[46]

Ecological Condition as an Environmental Result

Ecological condition, like human health, is a crucial measure of the results of environmental protection activities. As a regulatory agency, EPA has long monitored environmental stressors, as described in the chapters of this report on air, water, and land. However, as discussed earlier in this chapter, stressors alone are not good proxies for understanding the condition of an entire ecosystem. One might compare measuring ecosystem health to measuring the health of the economy. Economic indices such as the consumer price index integrate multiple indicators—prices of many consumer goods. Information on only one consumer product or one sector would not be enough to judge trends in national pricing or spending. Similarly, monitoring only stressors, rather than the living things that are stressed, or monitoring ecosystem attributes in isolation does not convey a full and accurate picture of ecological condition. Using ecological condition as an environmental result requires understanding the relationships between ecological condition (as described by the SAB's essential ecological attributes) and stressors that represent the focus of EPA's current responsibilities for environmental stewardship. EPA can build on decades of monitoring stressors while it develops and monitors appropriately multi-dimensional and better-linked ecological condition indicators. Some promising approaches to identifying such indicators are described below.

Many factors stress ecosystems. How ecosystems are affected varies significantly according to the nature of the stress, its duration and frequency, and the conditions in the ecosystem before the stress occurred. For instance, the flows and interactions related to sulfur and nitrogen oxides as air pollutants depicted in Exhibit 5-10 provide an example of the effects of stress in ecosystems. Arrows depict sulfur and nitrogen in different forms as they move through a watershed. Any of the components in Exhibit 5-10 could be measured as an indicator, but each alone contributes only a piece to the under-

Exhibit 5-10: Interaction among ecological variables



standing ecological condition. Monitoring the concentrations of pollutants at various points in the flow can contribute to understanding the effectiveness of pollution control programs. The success of a sulfur reduction program, however, can be assessed only by tracking whether lower sulfur emissions actually lessen sulfur concentrations in air, water, soil, fish, and forests.

Using this type of integrated approach, EPA and its partners were able to confirm that, following emissions reductions required by regulations under the 1990 Clean Air Act Amendments, acid rain decreased by 40 percent across broad areas of the northeastern and upper midwestern U.S. in the 1990s.[47] The decrease in acid rain itself was accompanied by significant reductions in the number of ecosystems affected by acid deposition.[48] Moreover, continuing regional lake and stream sampling has shown that in the Northeast, Upper Midwest, and Appalachians, one-quarter to one-third of lakes and streams previously affected by acid rain are no longer acidic (although they are still sensitive to changes in acid deposition).[49]

Just as important as measuring multiple variables is the choice of what to measure. In the case of sulfur in the ecosystem, measurements of emissions and conditions such as acidity of soil or water are not enough. Those measures do not provide any knowledge of the outcomes—the growth of trees or the health of fish. These biotic components are critical pieces in understanding the ecological condition of the system.

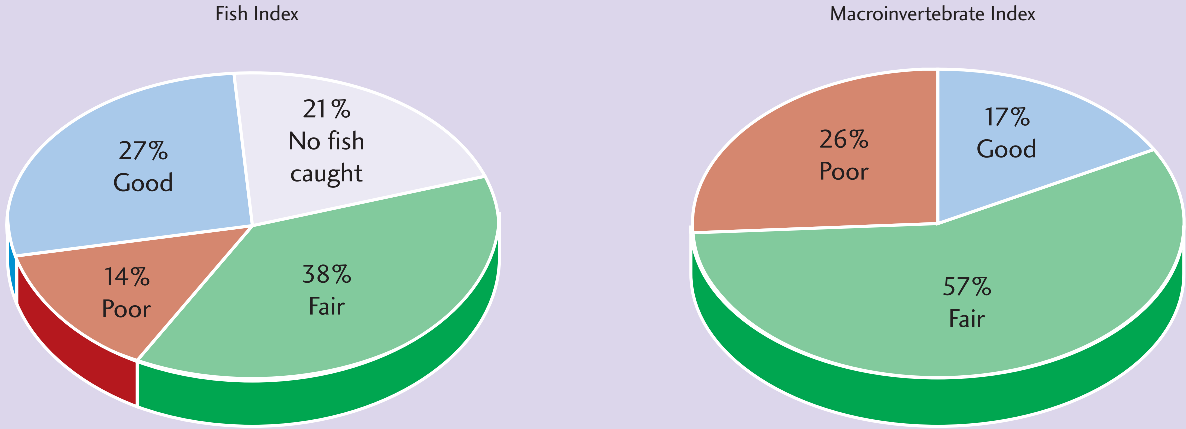
One approach that addresses the need to measure critical multiple variables is the index of biotic integrity (IBI), which has been applied with fish, bottom-dwelling invertebrates, and diatoms.[50] Just as the consumer price index combines the price of many consumer goods, the IBI combines measurements of a number of biological attributes, called "metrics," that reflect the ecological condition of a place, including biological diversity; relative abundance of indicator groups of organisms, such as predators, highly tolerant species, or non-native species; the health of individual organisms; and ecological relationships such as food web structure.[51]

In a demonstration project in mid-Atlantic streams, EPA applied a fish IBI along with measurements of several prominent stressors. In a statistical sample of streams representing 90,000 total stream miles, IBI was used to evaluate the biological differences between minimally altered reference streams in the region and streams with varied levels and types of stressors. The study revealed that sought-after sport fish declined in more turbid streams and in streams with increased streamside agriculture.[52] In addition, acidification lowered the number of minnow, bottom-dwelling, and sensitive species but raised the number of individuals belonging to non-native species. Regionally, the results indicated that 27 percent of the streams were in "good condition" relative to the reference streams that represented the best current conditions in the region (specifically, the IBIs of "good" streams ranked within the top 25 percent of reference stream IBIs), 38 percent were in "fair condition" (their IBIs ranked with the other 75 percent of reference streams), and 14 percent were in "poor condition" (below the lowest 1 percent of reference stream IBIs) (Exhibit 5-11).[53]

A macroinvertebrate IBI was also applied in the mid-Atlantic streams demonstration project. Stream conditions were classified in much the same way as with the fish IBI. Based on the macroinvertebrate IBI, 17 percent of the streams were in "good condition" (within the top 25 percent of reference stream IBIs), 57 percent were in "fair condition" (within the lower 75 percent of reference stream IBIs), and 26 percent were in poor condition (within the lowest 1 percent of reference stream IBIs) (Exhibit 5-11).[54]

These results are applicable regionwide, providing decision-makers with a clearer picture of the ecological condition in the region's streams, a catalog of specific biological responses associated with that condition, and insight about the effects of specific stressors on condition. Collectively, this knowledge

Exhibit 5-11: Fish and Macroinvertebrate Indices of Biotic Integrity



Note: No fish caught does not indicate poor condition. Some streams naturally do not have fish.

Source: McCormick F.H., et al. *Development of an Index of Biotic Integrity for the Mid-Atlantic Highlands Region.* 2001.

Source: Klemm D.J., et al. *Development and Evaluation of a Macroinvertebrate Biotic Integrity Index (MBII) for Regionally Assessing Mid-Atlantic Highlands Streams.* 2003.

tells policymakers which stressors need to be managed to protect or restore ecological condition.

In sum, using ecological condition as an outcome of environmental protection efforts will require monitoring strategies that take into account both of the following:

- The stressors—factors, activities, or variables—that create or contribute to changes in ecological attributes (e.g., changes in biotic condition or ecological processes; changes in habitat pattern and extent; physical, chemical, and hydrologic changes; and changes in natural disturbance regimes).
- The actual outcomes of EPA's efforts to control these factors and actions (e.g., wetland protection, pollution reduction or prevention, registration of pesticides, proper waste disposal, public information)—that is, whether EPA's efforts maintain or improve ecological condition.

Challenges in Developing Ecological Condition Indicators

Americans recognize the value of consistent and unbiased surveys of indicators focused on the state of the economy as elements in maintaining a strong economy. Such surveys develop and track numbers on poverty, agricultural productivity, consumer prices, housing starts, and a host of business parameters. Each of these indicators is backed by a process for collecting and reporting the information and a sound rationale for its use as one indicator of economic condition.

Although not everyone understands the exact calculations or data sources, almost everyone seems to pay close attention to the indicators' ups and downs.

No comparable system exists to measure the ecological state of the nation. As a result, adequate data for nationwide trends exist for only a few indicators of ecological condition (shown by the solid circles in Exhibit 5-12). Other indicators (open circles) do have some data, but the data have only been collected once or for limited geographic regions. The clear message is that most of the data needed to track ecological condition have only begun to be collected, and only for limited parts of the nation thus far. This situation will improve over the next few years, but most of the gaps in Exhibit 5-12 are likely to remain for some time to come, because of several major challenges to developing adequate indicators of national ecological condition:

- Indicators must be tied to conceptual models that capture how ecosystems respond to single and multiple stressors at various scales.

- Federal, state, and local monitoring organizations must find a way to coordinate and integrate their activities to meet multiple, potentially conflicting, data needs.

- Mechanisms must be found to ensure long-term commitments to measuring selected indicators over long periods and in standardized ways, to establish comparable baselines and trends.

- Indicators must simplify complex data in ways that make them meaningful and useful to decision-makers and the public.

None of these challenges appears insurmountable, but the gaps in Exhibit 5-12 indicate that much remains to be done.

Exhibit 5-12: Distribution of available ecological indicators across the ecosystem types

Essential Ecological Attribute	Forests	Farmlands	Grasslands/ Shrublands	Urban/ Suburban	Fresh Waters	Coasts and Oceans	The Nation
Landscape Condition							
Extent of Ecological System/Habitat Types	●●	●	●	●	●●	●	●
Landscape Composition	○	●		○	○	○○	
Landscape Pattern/Structure	○						
Biotic Condition							
Ecosystems and Communities	○		●○		○○○○○	○○○	○
Species and Populations	○				○	○	○
Organism Condition	●○○				○	○○	
Ecological Processes							
Energy Flow							●
Material Flow	○						●
Chemical and Physical Characteristics							
Nutrient Concentrations	○	○○		○○	○○	○○	
Other Chemical Parameters	○○				○	○○	
Trace Organic/Inorganic Chemicals		○○○○		●○	○	○○	○
Physical Parameters	○					○	
Hydrology and Geomorphology							
Surface and Ground Water Flows	●		●		●		
Dynamic Structural Conditions							
Sediment and Material Transport	○	○○			○		
Natural Disturbance Regimes							
Frequency	○						

● Adequate national data for assessing condition ○ Limited national data for assessing condition

Note: Each circle, whether open or solid, represents an indicator presented in the Technical Document.

Endnotes

[1] Chapter 5 – Ecological Condition, of the Report on the Environment Technical Document accompanying this report is organized differently, posing questions about the condition of various ecosystem types and presenting a broader set of indicators that report on essential ecological attributes for each ecosystem type.

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[22] Ibid.

[23] Ibid. Based on data from the U.S. Geological Survey, Biological Resources Division.

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